Demonstration of Advanced Ensemble Prediction Services for NWS Hydrometeorological Forecast Operations: Preliminary work

2015 South Carolina Floods
(National Weather Service Columbia, SC)

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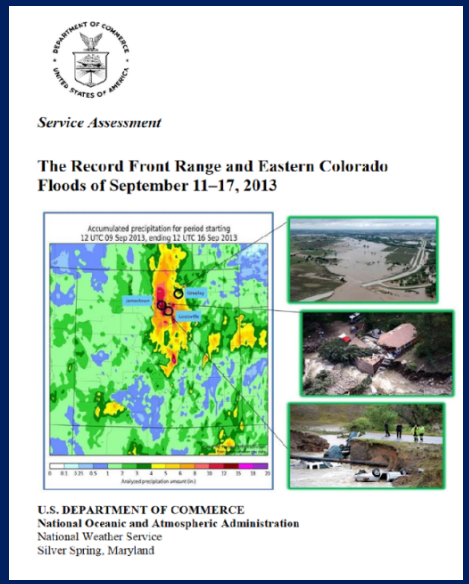
2016 7th NOAA Testbeds and Proving Grounds Workshop
College Park, MD

Motivation

Recent events and NWS strategic documents cite improvements needed in:

1. Flash flood guidance
2. Hydrological process representation in models (both at River Forecast Centers & Weather Forecast Offices)
3. Hydrometeorological ensemble methodologies: better characterize forecast uncertainty
4. Communication of hydrometeorological forecasts: risks and uncertainties → support risk-based decision-making



Service Assessment

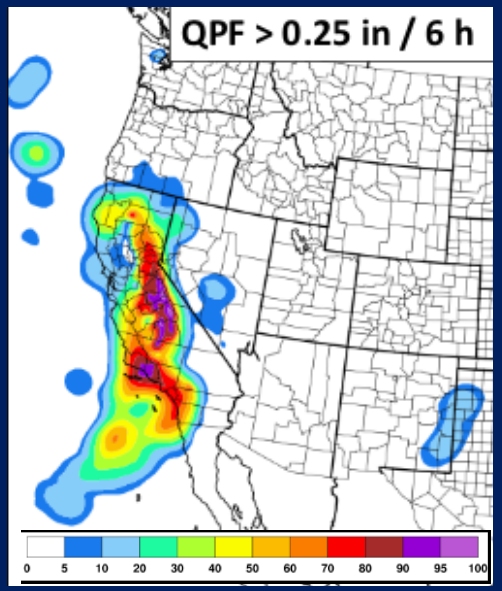
The Record Front Range and Eastern Colorado Floods of September 11–17, 2013

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

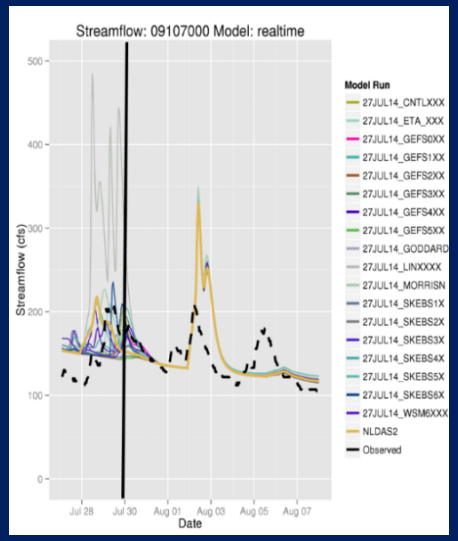
2015 – 2017 HMT-USWRP Project: Demonstration of Advanced Ensemble Prediction Services for NWS Hydrometeorological Forecast Operations

- Objectives:
  - Generate probabilistic short-range QPFs
  - Input into hydrologic model
  - Produce improved combined hydrometeorological forecasts
  - Develop in close collaboration with operational forecasters
- Project start date: 1 September 2015
- Multi-agency team:
  - Kelly Mahoney (NOAA/PSD)
  - Dave Gochis (NCAR)
  - Trevor Alcott (NOAA/GSD)
  - Daniel Nietfeld (NOAA/NWS/WFO Omaha)
  - Dave Reynolds (NOAA/ESRL/PSD, CIRES)
  - Rob Cifelli (NOAA/PSD)
  - Stan Benjamin (NOAA/GSD)
  - Brian Cosgrove (NOAA/NWC)
  - Chad Kahler (NOAA/NWS/WRH)
  - Mark Strudley (NOAA/NWS/WFO Monterey)

Example: HRRRX probabilistic quantitative precipitation forecast (QPF)

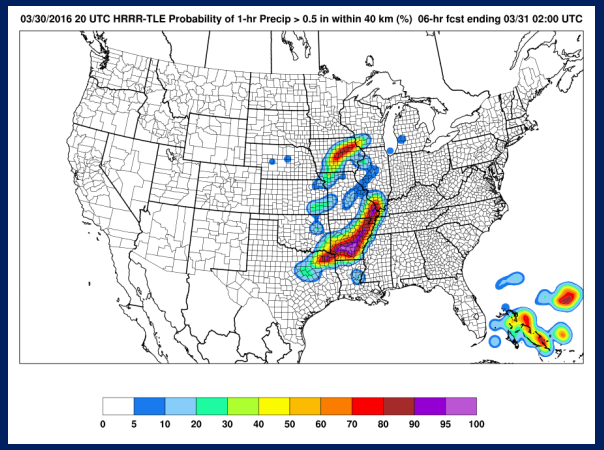


Example: WRF-Hydro ensemble streamflow forecast

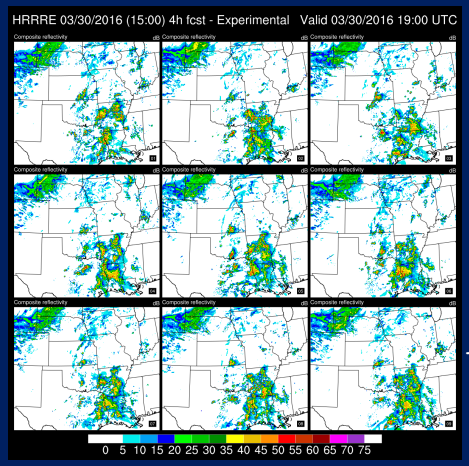


Precipitation forecasts from High Resolution Rapid Refresh (HRRR) model

- Current operational version of HRRR
  - 3-km
  - *Deterministic*
- Probabilistic HRRR efforts being developed
  - Initial proof-of-concept for driving WRF-Hydro ensemble: Use time-lagging methods
    - NOAA ESLR GSD's HRRR Time-lagged ensemble (HRRR-TLE)
    - http://rapidrefresh.noaa.gov/hrrrtle/
  - Ongoing development: Use experimental HRRR ensemble
    - In proof-of-concept stage in NOAA ESRL GSD
    - http://rapidrefresh.noaa.gov/HRRRE/



HRRR-TLE Probabilistic forecast of 1-hr precip > 0.5 inches within 40-km



HRRRE composite reflectivity forecast across all 9 ensemble members

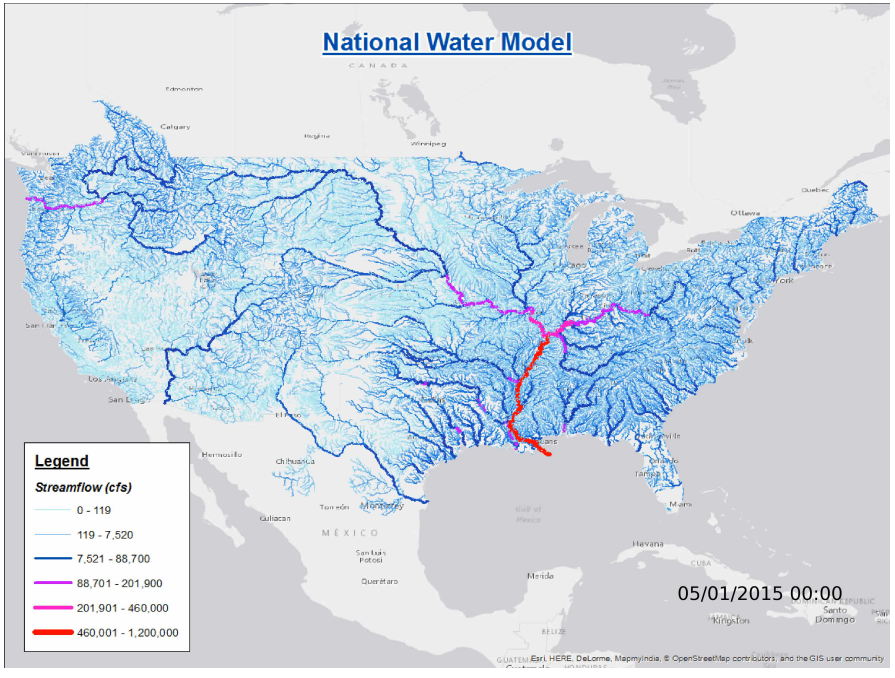
Hydrologic forecasts generated by WRF-Hydro: National Water Center operational configuration

NWC NATIONAL WATER CENTER

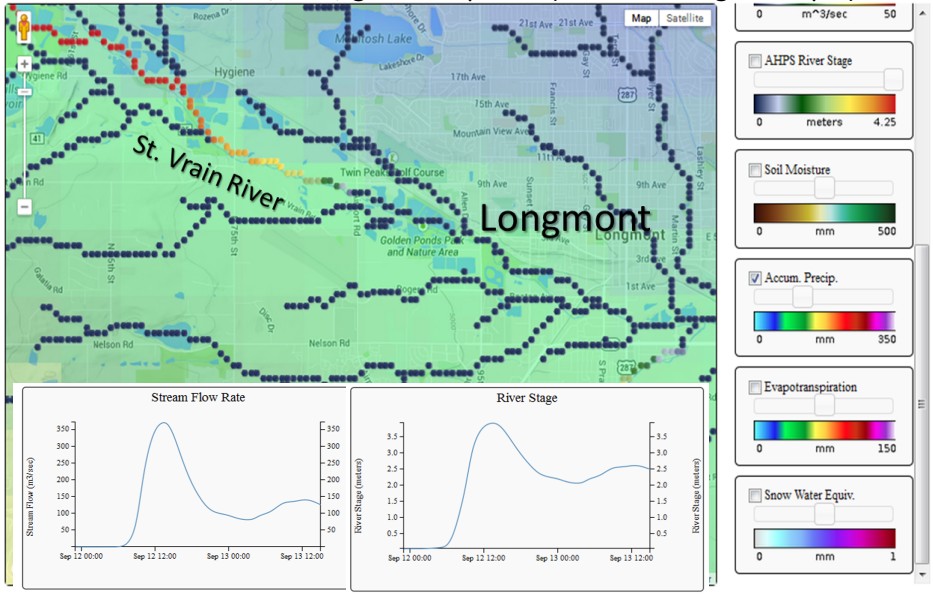
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

National Water Modeling Initial Operating Capability (IOC):

- Operational forecast streamflow guidance for currently underserved locations (~4,000 → 2.7 million river reaches)
- Spatially continuous estimates of hydrologic states for the nation through enhanced physical accounting of major water cycle components
  - snowpack, soil moisture, ET, channel flow, flood inundation

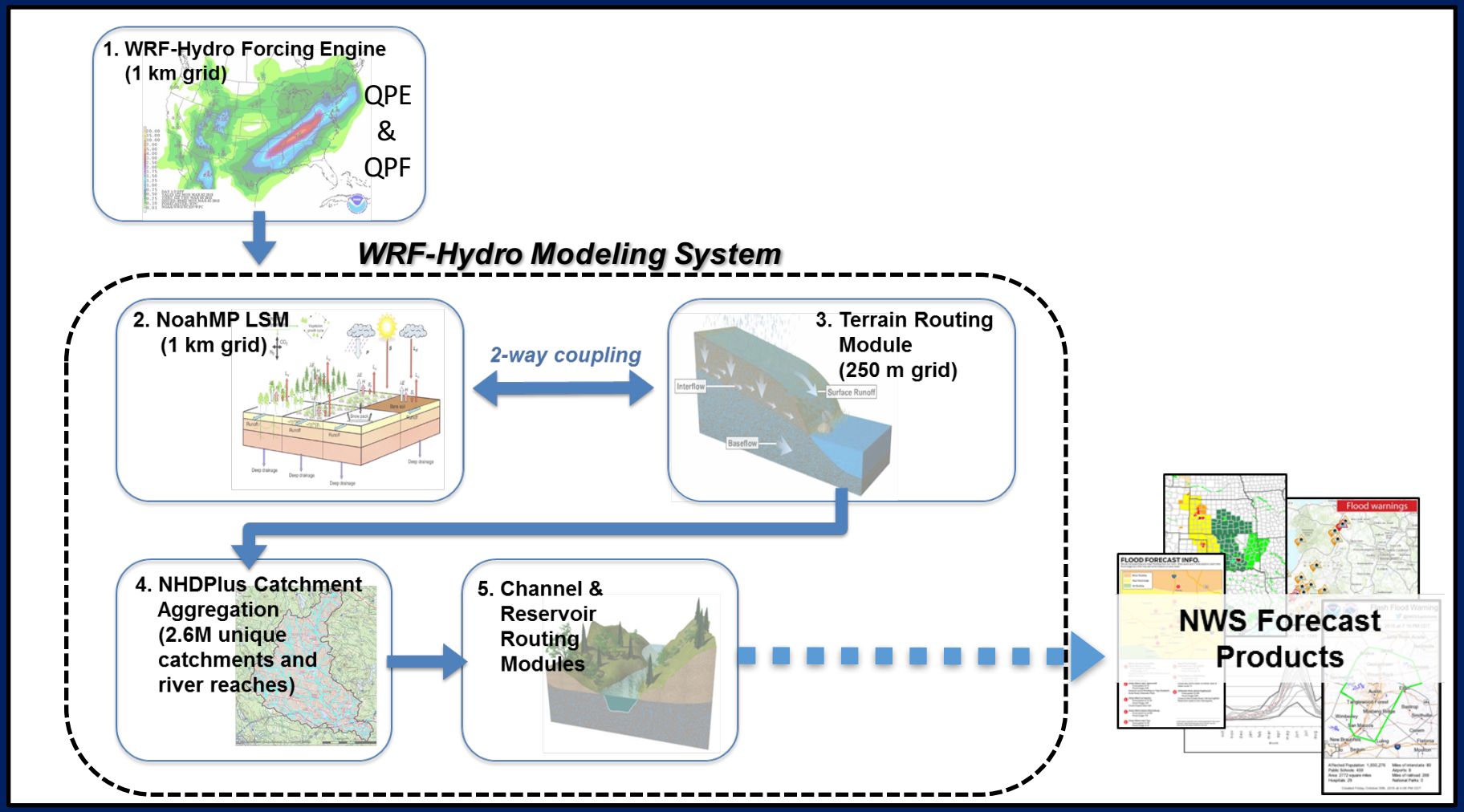


WRF-Hydro Modeled Streamflow, River Stage + Soil Moisture, ET, SWE, gridded options (CO Front Range Example)



WRF-Hydro/National Water Model v1.0:

- Target operational date: mid-June 2016
- System Configuration:

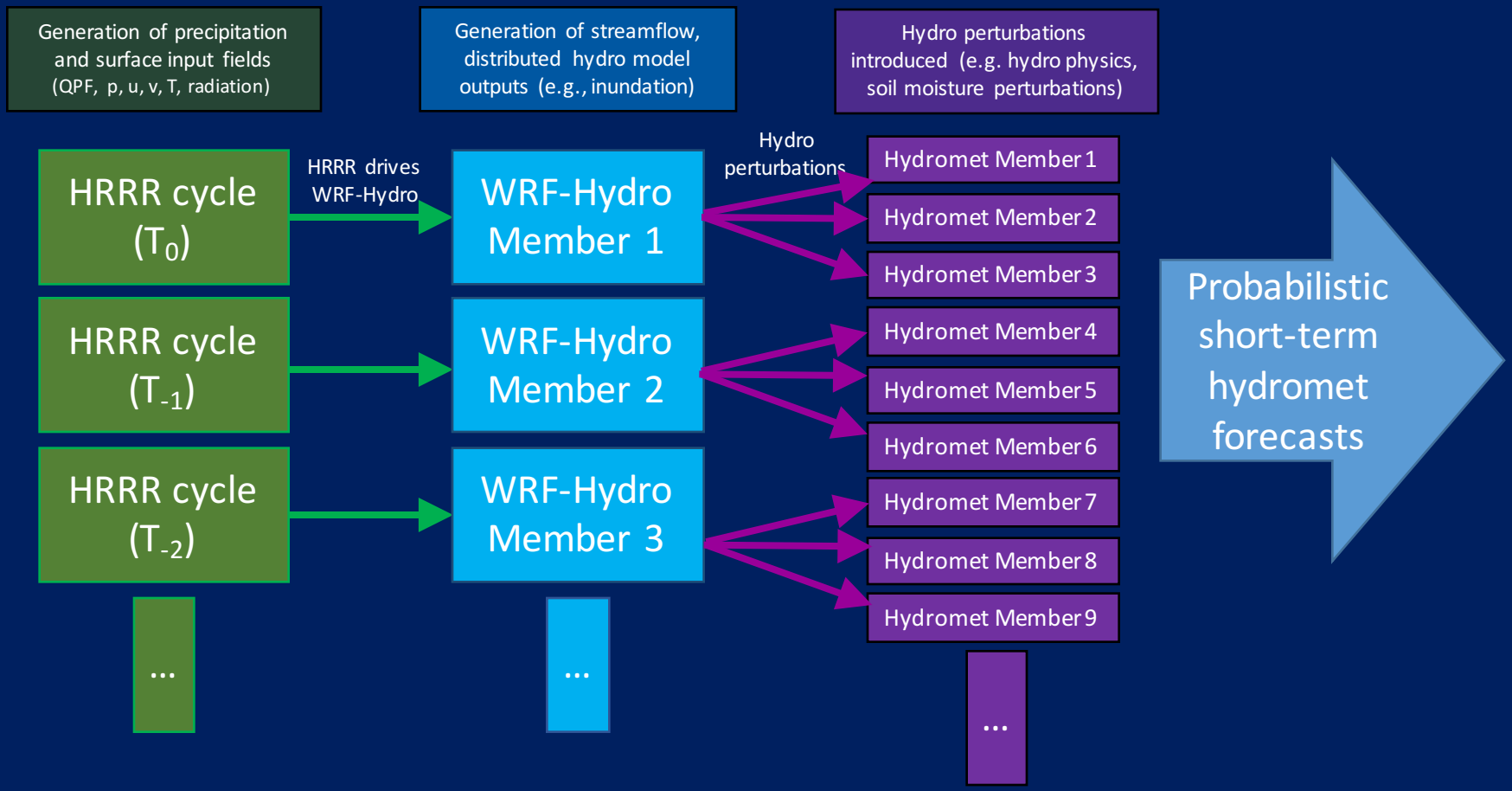


WRF-Hydro/National Water Model v1.0: Analysis and Forecast Cycling Configurations

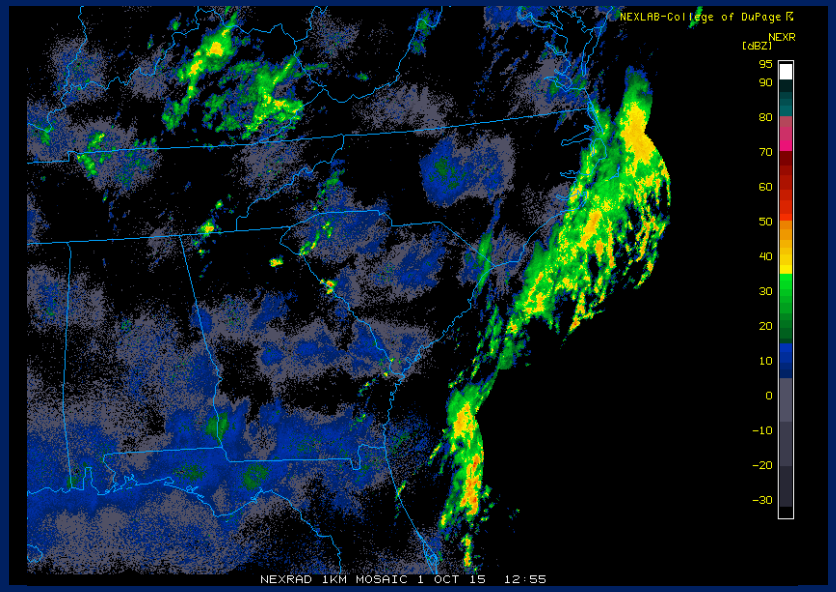
	Cycling	Forecast	Meteorological Forcing	Outputs
	Hourly	0 – 18 hrs (deterministic)	MRMS QPE Downscaled HRRR/RAP Blend	1-km spatial fluxes (water & energy); 250-m routed fluxes (water); NHDPlus channel routing
	Daily	to 10 days (deterministic)	Downscaled GFS	1-km spatial fluxes (water & energy); 250-m routed fluxes (water); NHDPlus channel routing
	Daily x 16 (ensembles)	to 30 days	Downscaled & NLDAS2 Bias Corrected CFS	1-km spatial fluxes (water & energy); NHDPlus channel routing

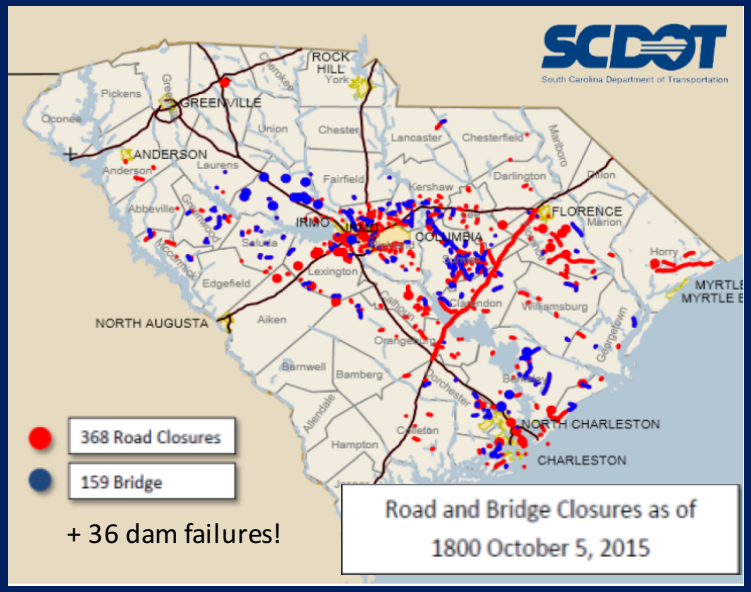
HRRR-Ensemble + WRF-Hydro Hydrometeorological Ensemble

- *Initial* hydrometeorological ensemble design
  - Testing using time-lagged HRRR "ensemble"
  - Future versions will use experimental HRRR ensemble members

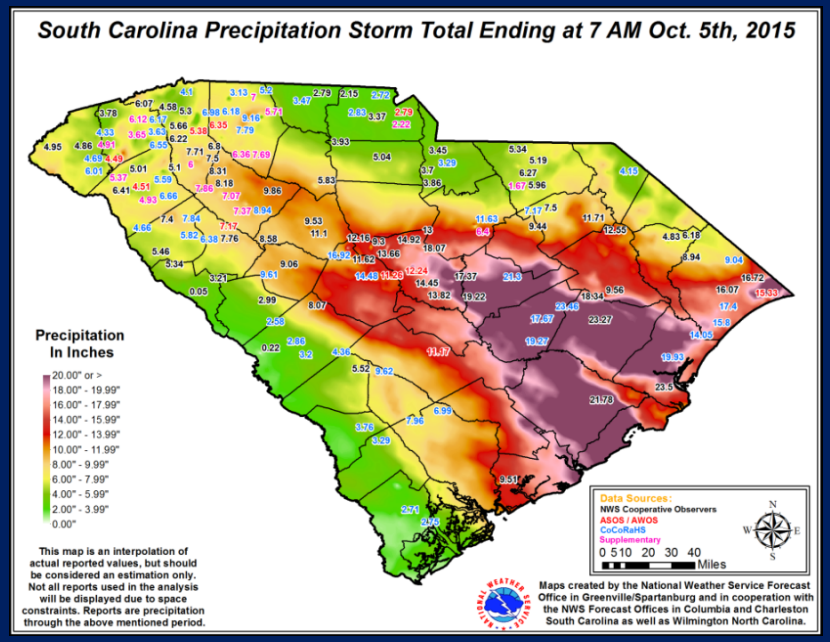


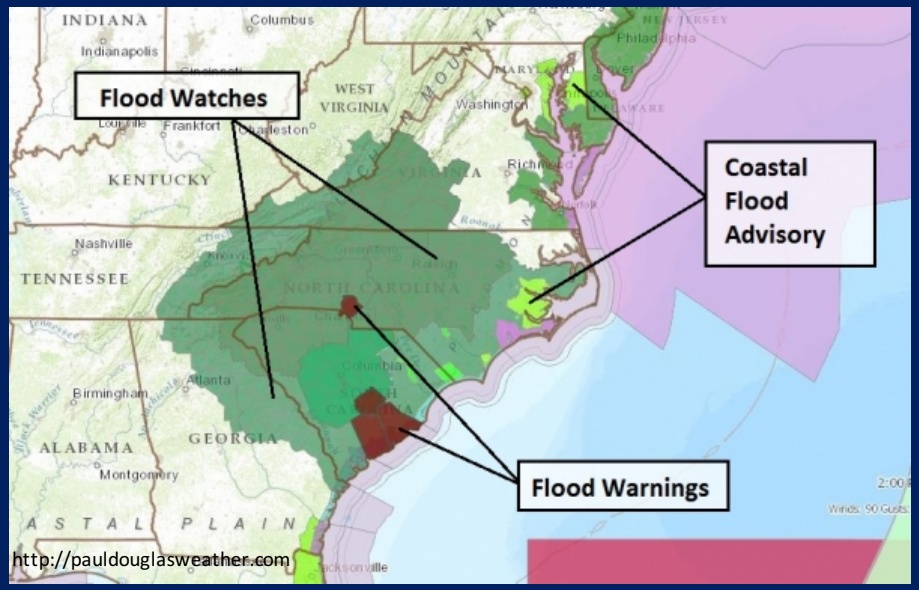
Case study:
October 2015 South Carolina flooding





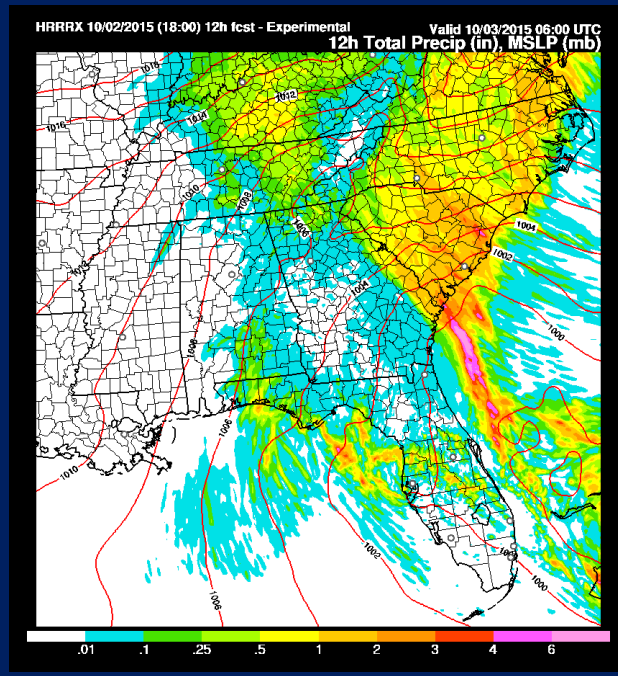
October 2015 South Carolina flooding: Forecast challenges



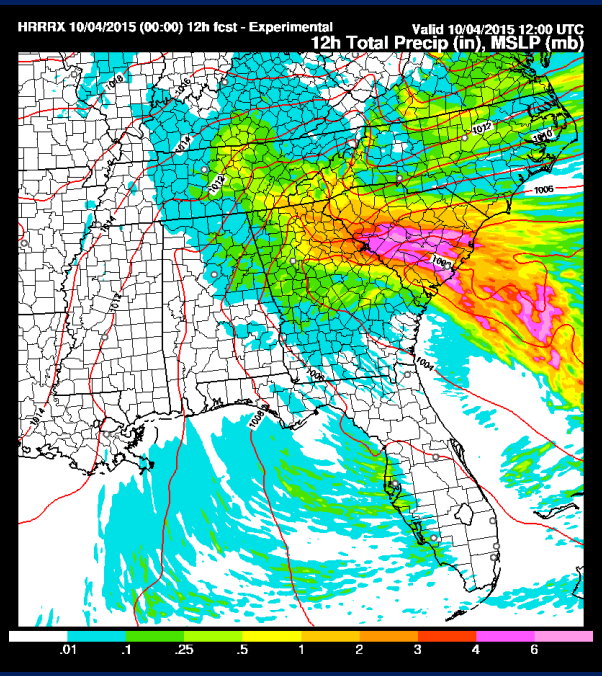


- Widespread, multi-day event: uncertainty in track of Joaquin; models focusing heavy rainfall north of SC until 1-2 days out reduced preparedness
- Challenges once rainfall began: precip gradients, hydrologic response times, ultimate flood depth and duration, anticipation of impacts
- Highlights gaps in coupled hydrometeorological forecast guidance at both medium- and short-range time and space scales

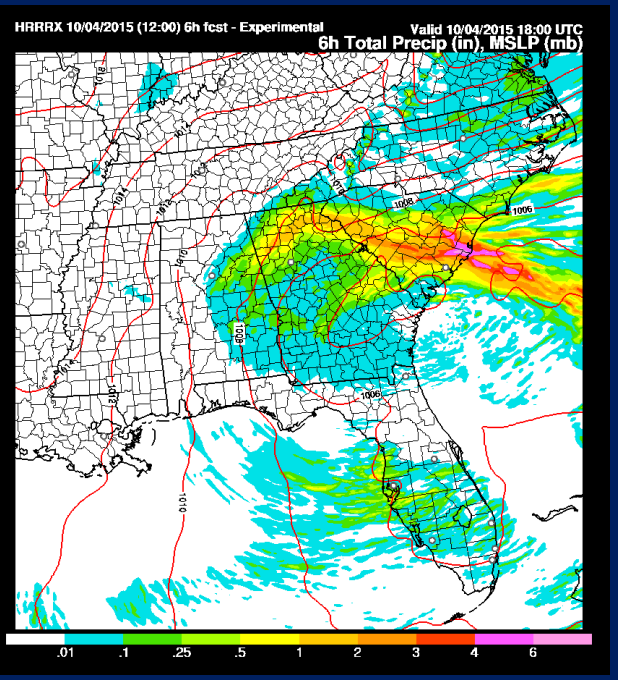
October 2015 South Carolina flooding: HRRRX forecasts throughout event



12-h HRRRX QPF early in event
(06 UTC 3 Oct)



12-h HRRRX QPF mid-event
(12 UTC 4 Oct)

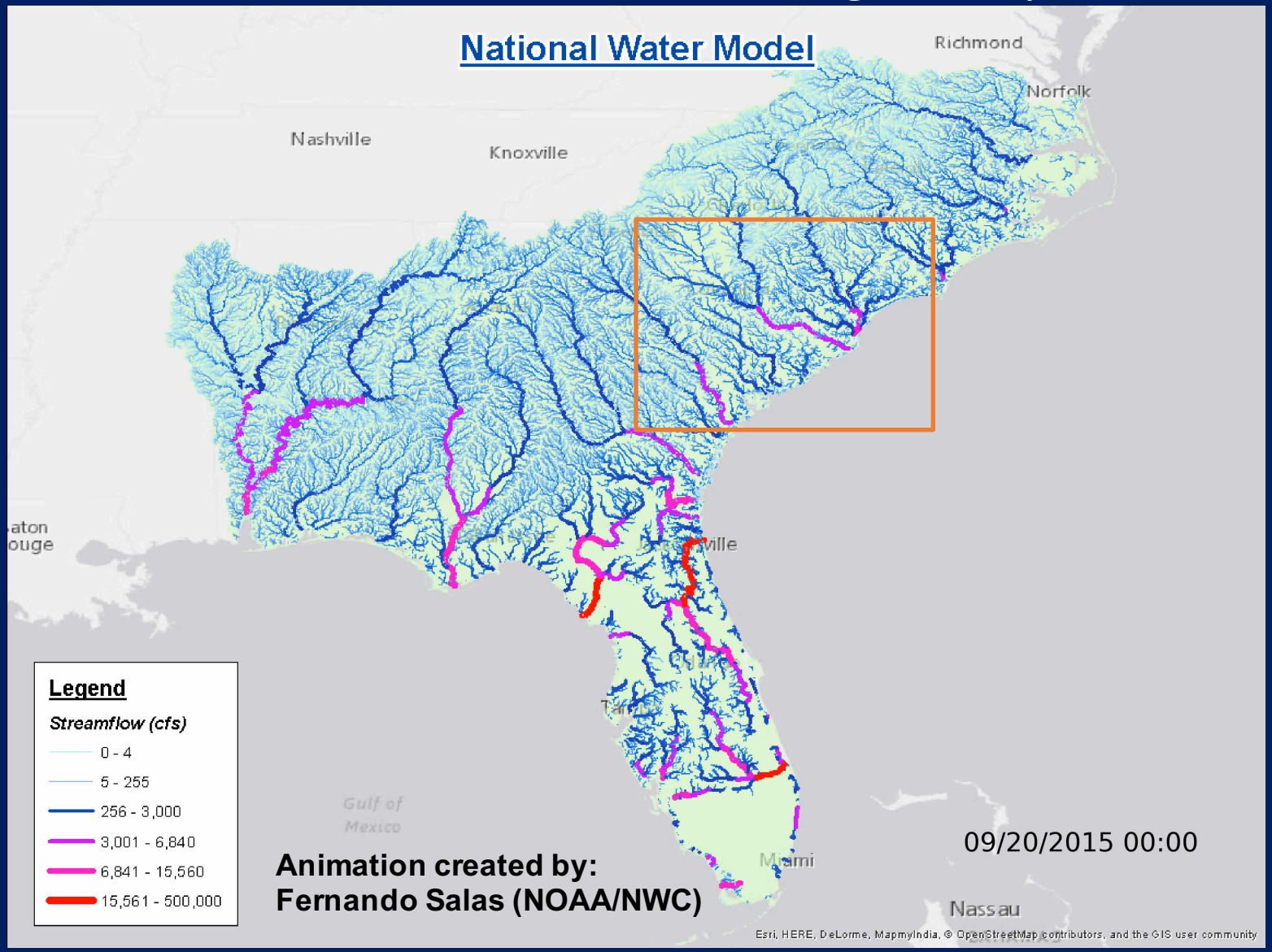


6-h HRRRX QPF later in event
(18 UTC 4 Oct)

- HRRR indicated heavy precipitation; important mesoscale details shifted in some key runs
- Time-lagging uses already-available runs to increase model forecast sample size
- 100+ HRRR cycles run through WRF-Hydro

Results: Analysis-driven WRF-Hydro simulation

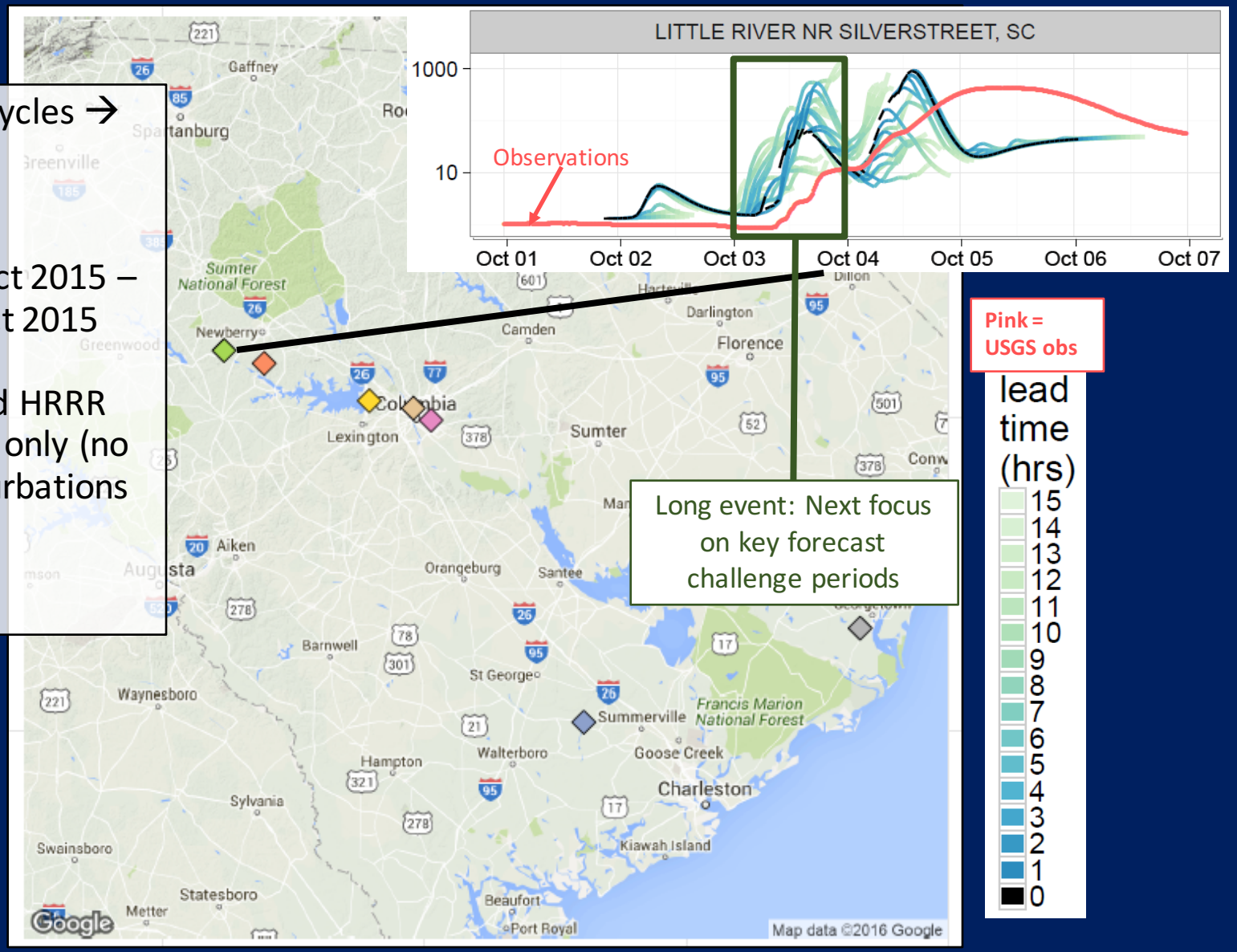
Streamflow animation: MRMS driving WRF-Hydro



Results:
HRRR Time-lagged ensemble-driven WRF-Hydro forecasts

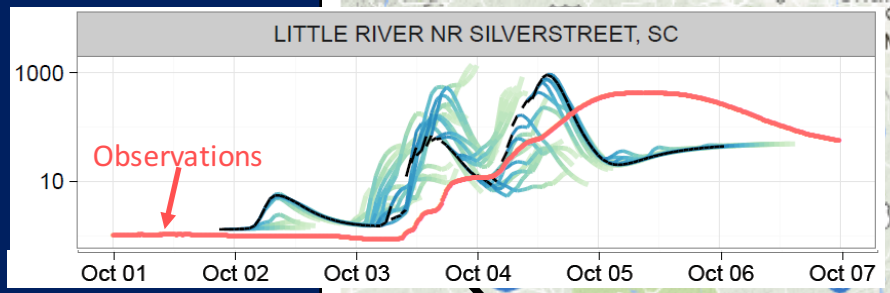
Streamflow Hydrographs (units cms) [note: uncalibrated, no DA, no QPF bias-correction]

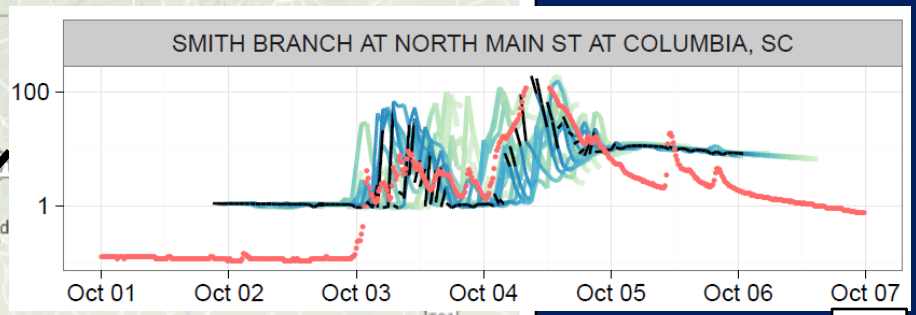
- 100 HRRR cycles → WRF-Hydro simulations
- 21 UTC 1 Oct 2015 – 00UTC 6 Oct 2015
- Time-lagged HRRR driven runs only (no hydro perturbations yet)

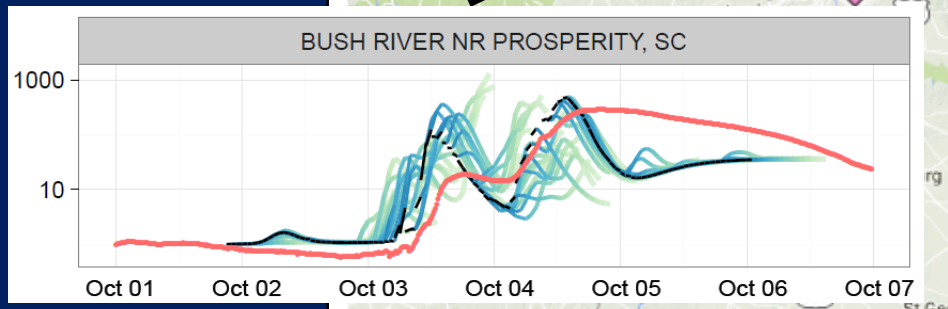


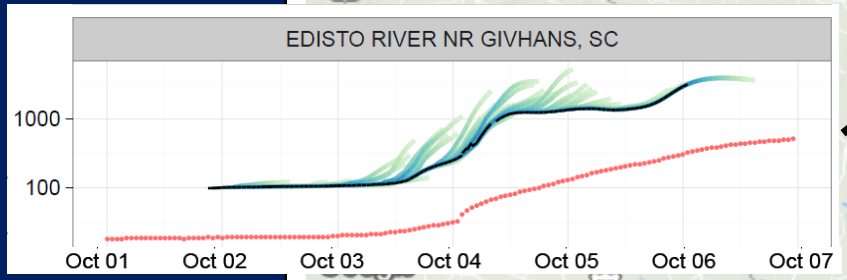
Results:
HRRR Time-lagged ensemble-driven WRF-Hydro forecasts

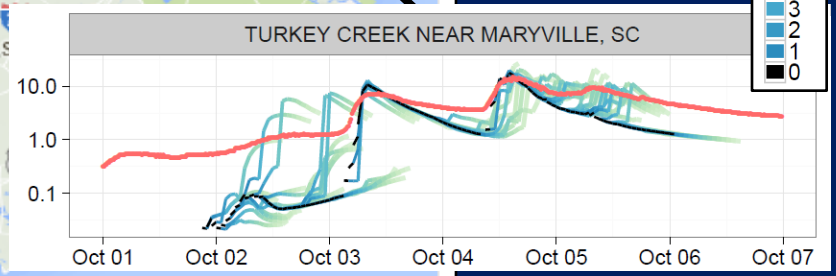
Streamflow Hydrographs (units cms) [note: uncalibrated, no DA, no QPF bias-correction]



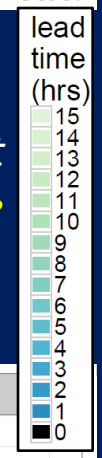






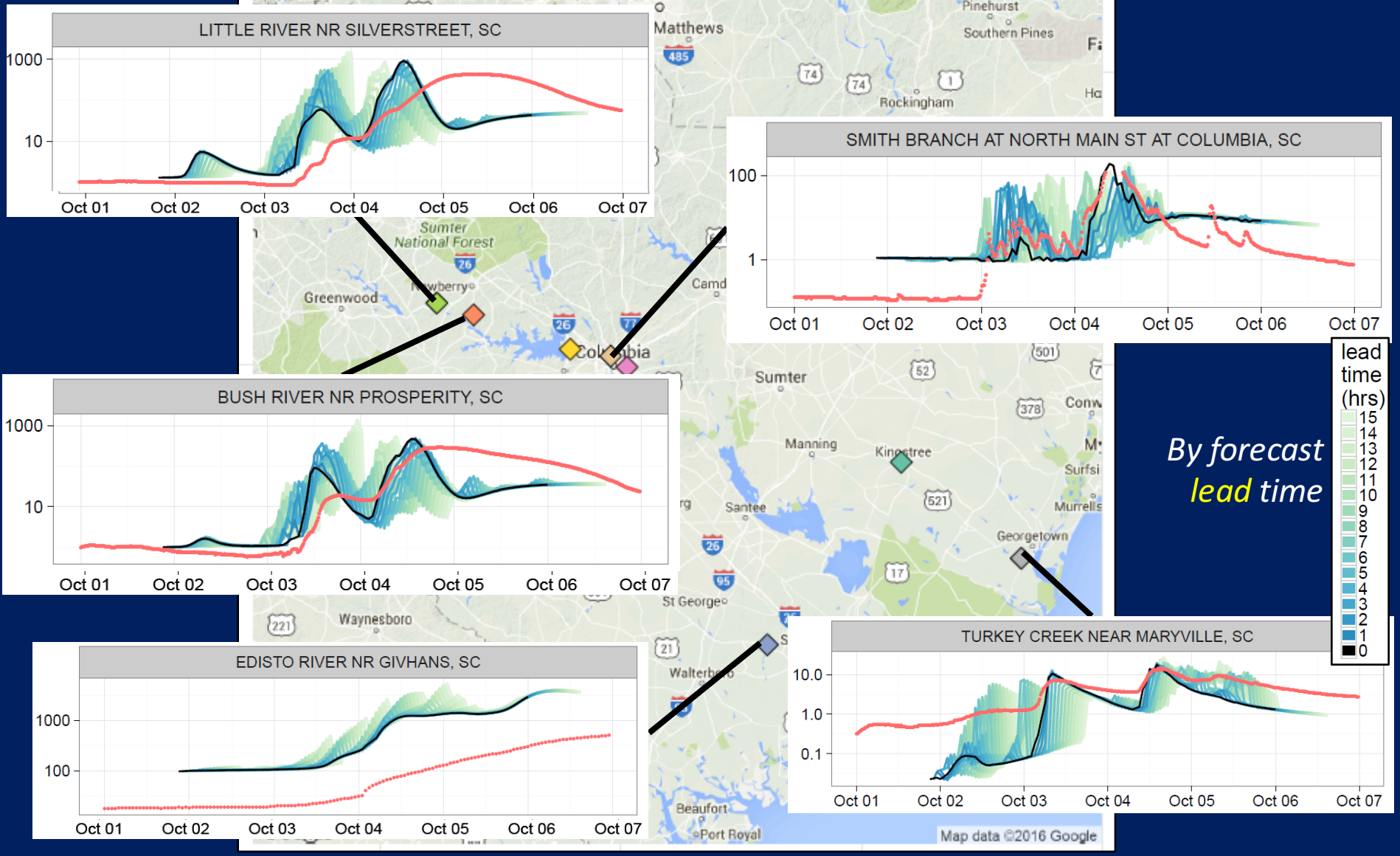


By forecast cycle



Results:
HRRR Time-lagged ensemble-driven WRF-Hydro forecasts

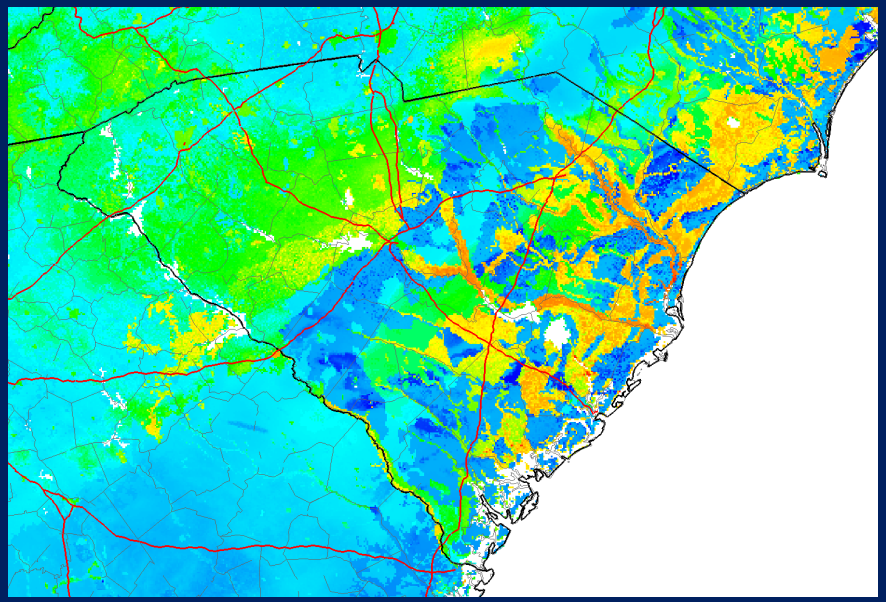
Streamflow Hydrographs (units cms) [note: uncalibrated, no DA, no QPF bias-correction]



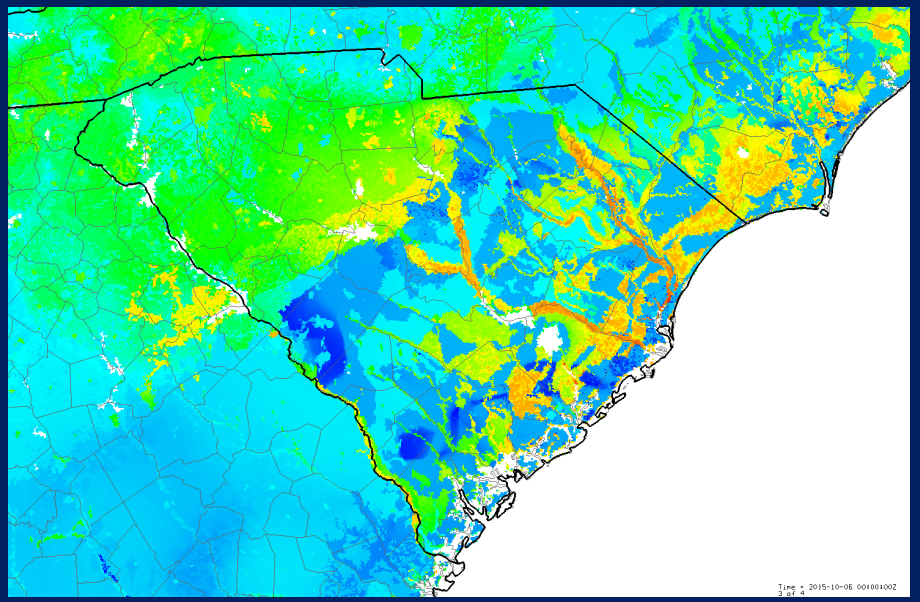
Results:
HRRR-driven WRF-Hydro forecast of Soil Saturation

(deterministic example of potential output)

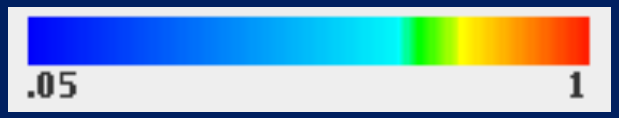
- HRRR-driven vs. Analysis-driven simulated % Soil Saturation



12hr HRRR-driven WRF-Hydro Forecast
Valid: 00UTC 06 Oct 2015



MRMS-driven WRF-Hydro Analysis
Valid: 00UTC 06 Oct 2015

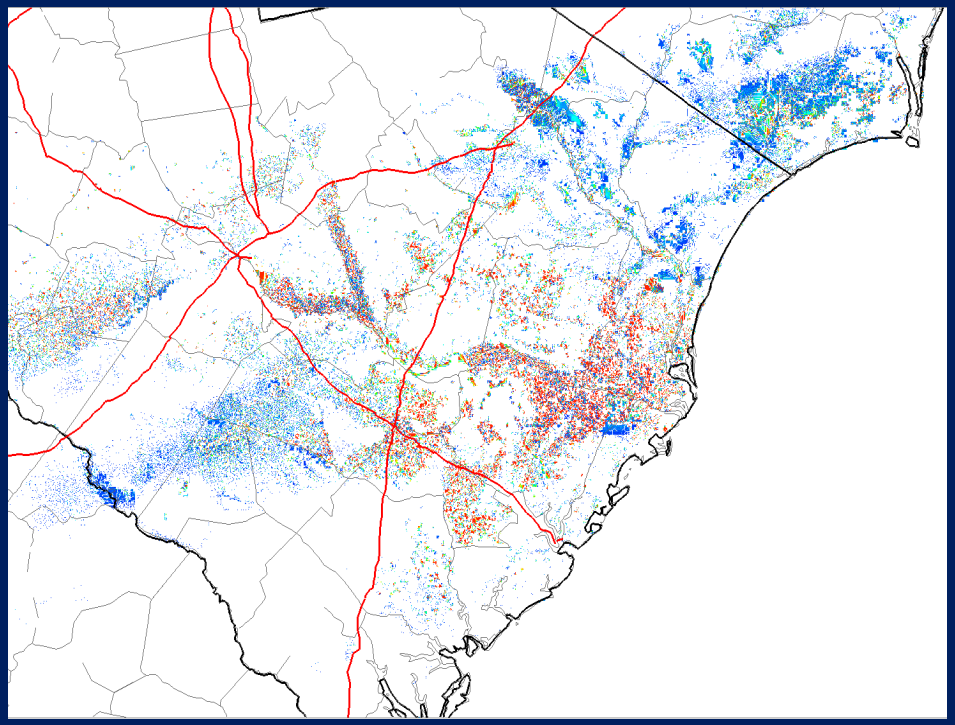


% Soil Saturation (top 2 soil layers)

Results:
HRRR-driven WRF-Hydro forecast of Surface Inundation

(deterministic example of potential output)

- HRRR-driven vs. Analysis-driven simulated surface inundation (mm)



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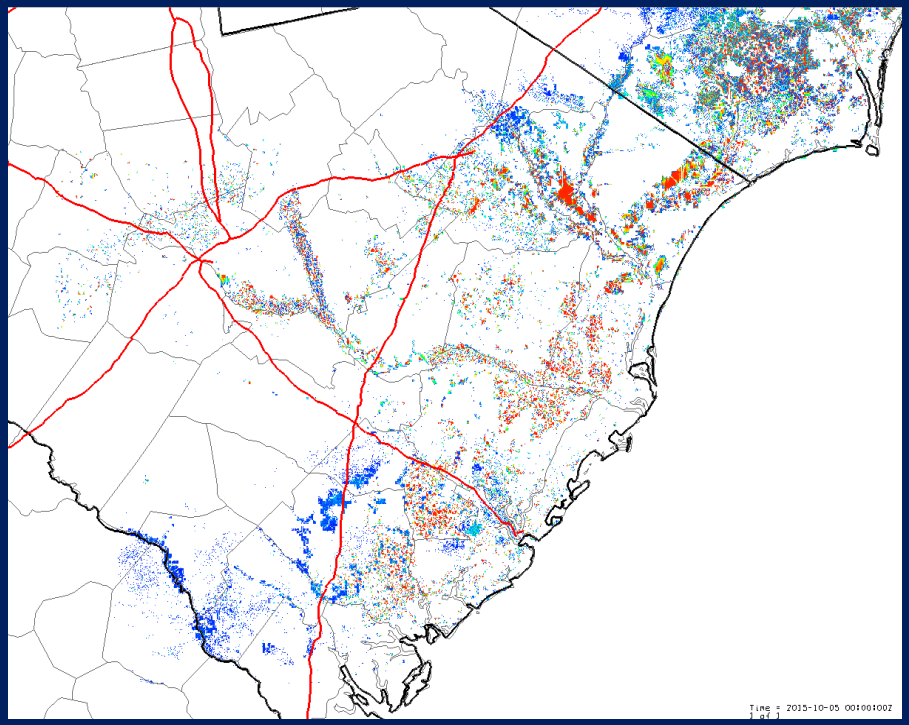

MRMS-driven WRF-Hydro Analysis
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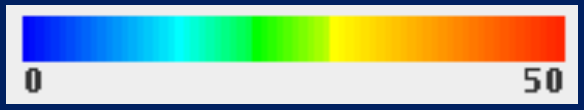
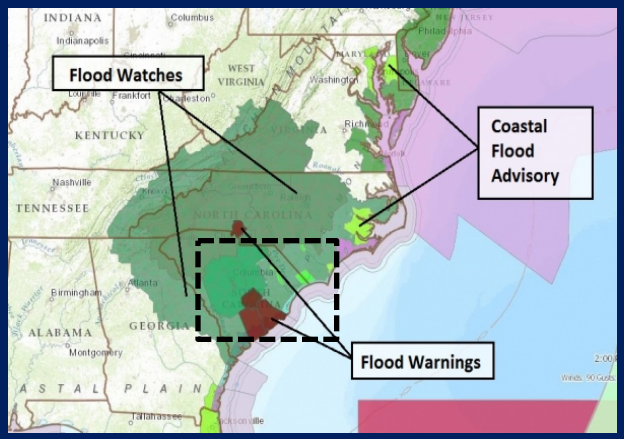


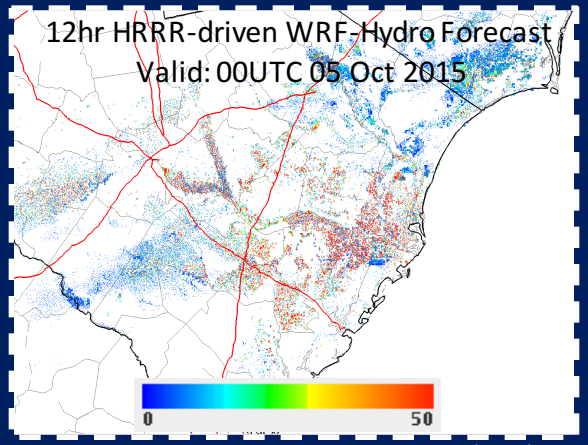
Surface Water Inundation Depth (mm)
[Max values up to +1000 mm]

Next steps

- Run hydrometeorological ensemble on retrospective events occurring across different regions, seasons, space/time scales
- Incorporate HRRR experimental ensemble
- Develop forecast products targeted toward bridging identified gaps between weather, water forecast(er)s
- Maintain continuous dialogue with WPC FFaIR, WFO, RFC forecasters to evaluate potential value of tools
- Develop products that can both differentiate and combine atmospheric/ hydrologic uncertainty
- Integrate impacts, hazards, risk assessment information

NWS Flood guidance vs. HRRR-WRF-Hydro Model Forecast





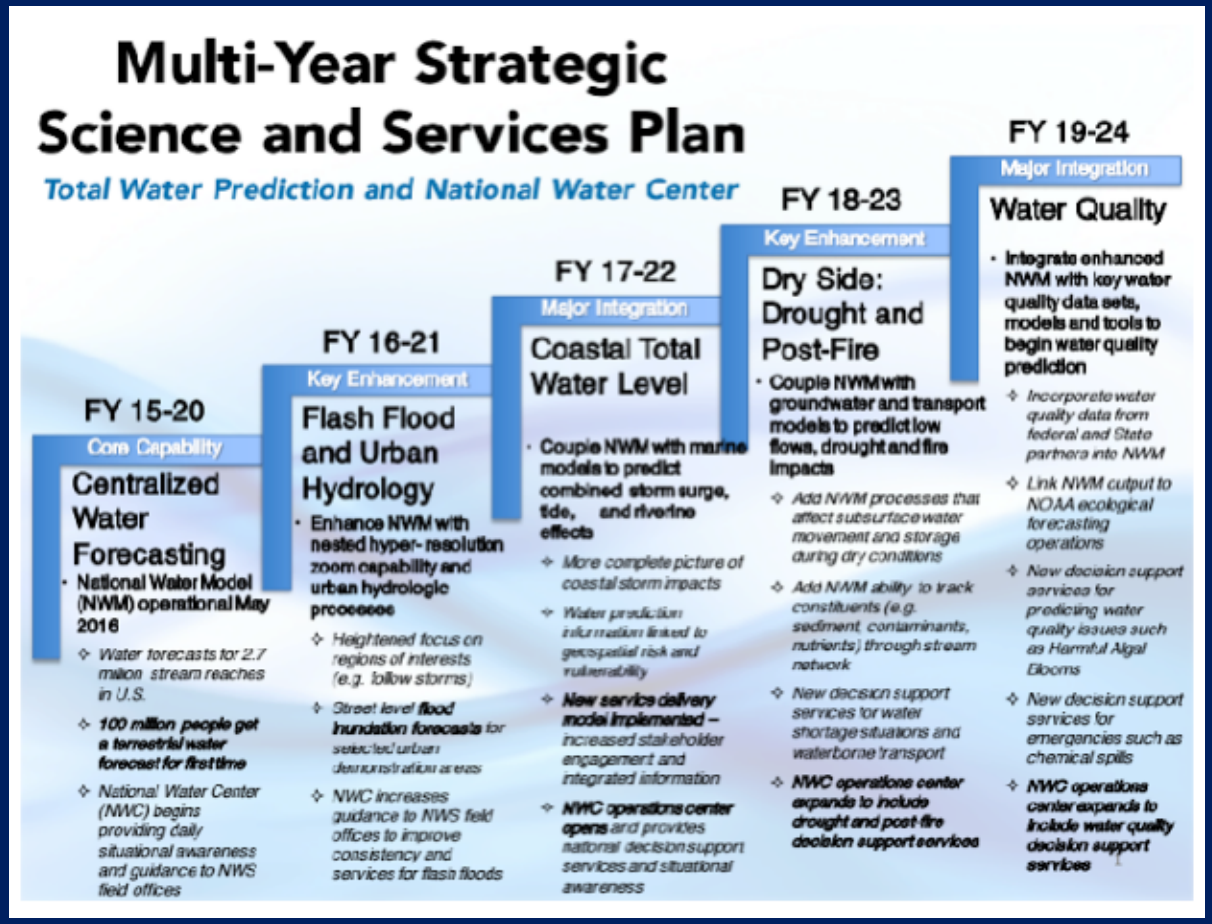
Surface Water Inundation Depth (mm)
[Max values up to +1000 mm]

Acknowledgements

- This material is based upon work supported by the U.S. Weather Research Program within NOAA/OAR Office of Weather and Air Quality under award via CIRES/NOAA Agreement NA12OAR4320137
- Jeff Waldstreicher, George McKillop: NWS Eastern Region Headquarters
- Frank Alsheimer, Leonard Vaughn: NWSFO Columbia, SC
- Todd Hamill, Christopher Schaffer: NWS Southeast River Forecast Center
- Chad Kahler, NWS Western Region Headquarters
- David Dowell, Curtis Alexander: NOAA ESRL GSD

Questions?
Kelly.Mahoney@noaa.gov

National Water Center Strategic Plan



http://mashable.com/2015/10/03/charleston-flooding/

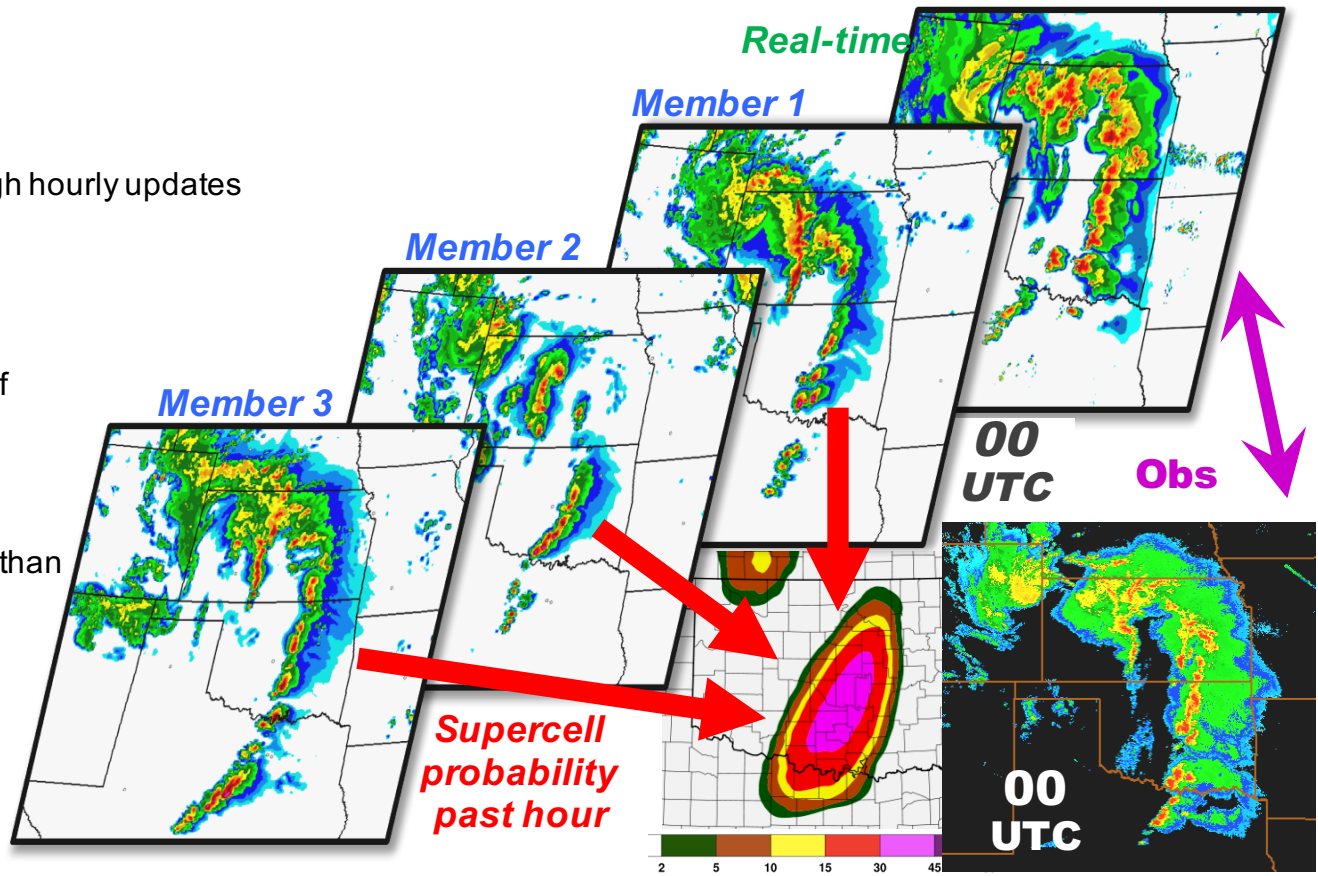
HRRR Time-Lagged Ensemble (HRRR-TLE)

Deterministic HRRR:

- High-resolution forecast
- Fresh forecast always available through hourly updates

Time-Lagged Ensemble (HRRR-TLE):

- "Ensemble of opportunity" (synthesis of available deterministic forecasts)
- Hazard likelihood probabilities
- Less small-scale detail in probabilities than in individual forecasts
- Proxy for confidence/certainty
- Underdispersion

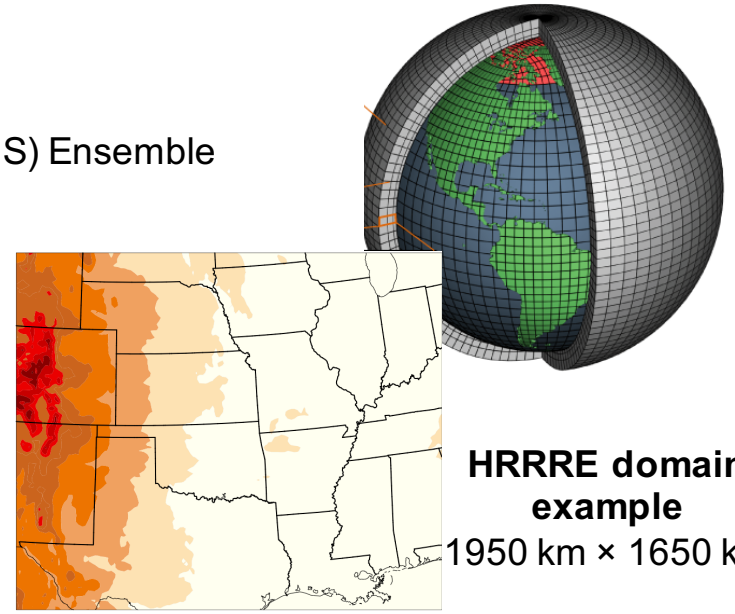


HRRR-TLE

Experimental HRRR Ensemble (HRRRE)

Real-time Tests

- March – June 2016
- Initial perturbations from NCEP Global Forecast System (GFS) Ensemble
- HRRR-like, but smaller domain
- 6+ forecast members
- More spread than in time-lagged ensemble
- Increased skill?



HRRRE domain example
1950 km × 1650 km

Retrospective Tests

- 27 April 2011 tornado outbreak in southeast US
- 23 – 24 May 2015 Blanco and San Marcos River (Wimberley, TX) flood (coming soon)
- 25 – 26 May 2015 Houston, TX flood (coming soon)
- 2 – 4 October 2015 South Carolina flood (coming soon)

HRRRE

Hydrometeorological Design Studies Center
National Water Center, National Weather Service
National Oceanic and Atmospheric Administration
1325 East-West Highway, Silver Spring, MD 20910
E-mail: HDSC.questions@noaa.gov

Updated: 6 October 2015

The Hydrometeorological Design Studies Center (HDSC) analyzed annual exceedance probabilities (AEPs) of the worst case rainfall for the South Carolina rainfall event that occurred during 2 - 4 October 2015. The rainfall event delivered rainfall amounts that exceeded 20 inches in 48 hours in some locations.

AEP is probability of exceeding a given amount of rainfall for a given duration at least once in any given year at a given location. It is an indicator of the rarity of rainfall amounts and is used as the basis of hydrologic design. The rarity of this event is illustrated in three figures below. Figure 1 shows how the maximum observed rainfall amounts compared to corresponding rainfall frequency estimates for AEPs from 1/10 (10%) to 1/1000 (0.1%) for durations from 1-day to 60-day for a rain gauge in South Carolina - US1SCCR0069, Mount Pleasant 6.4 NE (32.89655°N, 79.796166°W). The rain gauge is part of the Community Collaborative Rain, Hail & Snow Network (CoCoRaHS). The AEPs are estimates from the NOAA Atlas 14, Volume 2. As can be seen from Figure 1, observed rainfall amounts have annual exceedance probabilities of significantly less than 1/1000 for all durations from 2-day to 60-day (ending on October 5).

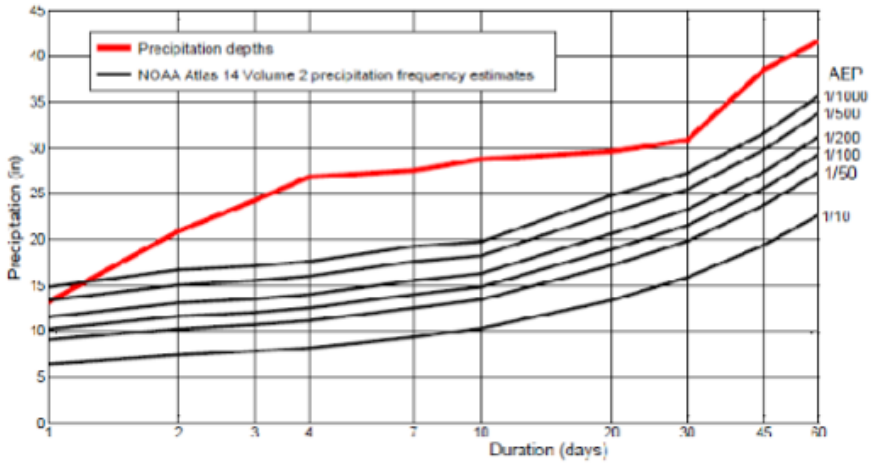


Figure 1. Maximum observed rainfall amounts in relationship to corresponding precipitation frequency estimates for the US1SCCR0069 *gauge.*

The maps in Figures 2 and 3 show the areas that experienced rainfall magnitudes with AEPs ranging from 1/10 (10%) to smaller than 1/1000 (0.1%) for the 24-hour and 72-hour duration, respectively. The 24-hour and 72-hour durations were selected as examples; maps for other daily durations look similar to the 72-hour map. Note that the beginning and ending of the worst case observation period is not necessarily the same for each location. As a result, these maps don't represent isohyets at any particular point in time, but rather the whole event. Rainfall amounts are derived from the National Centers for Environmental Prediction (NCEP), Environmental Modeling Center's (EMC) Stage IV analysis. Rainfall frequency estimates are from the NOAA Atlas 14, Volume 2.

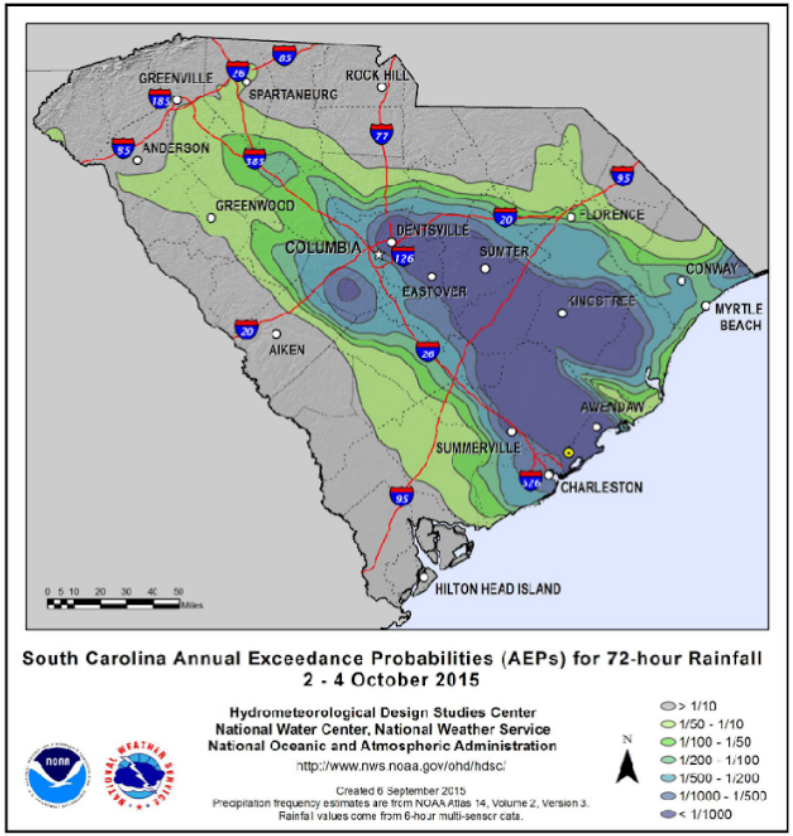
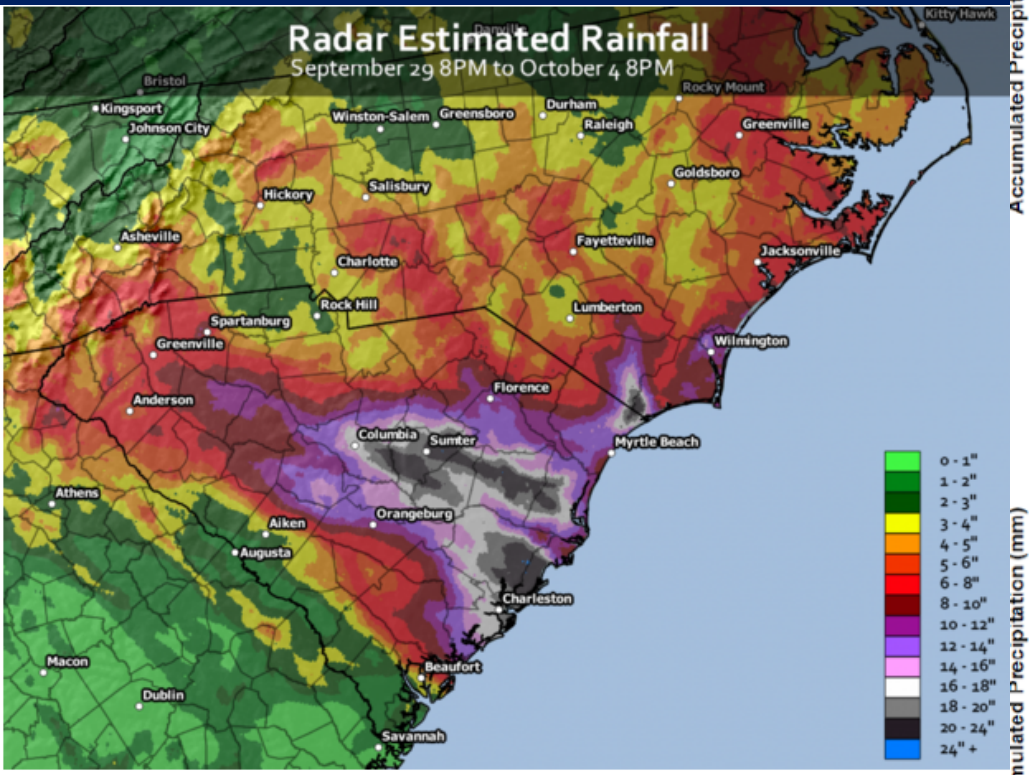


Figure 3. Annual exceedance probabilities for the worst case 72-hour rainfall from 2 to 4 October 2015. The yellow marker is the location of the US1SCCR0069 CoCoRaHS gauge.

SC Case - misc



A preliminary map of rainfall totals, estimated from radar, shows the vast extent of the deluge across most of South Carolina and parts of coastal North Carolina. The National Weather Service notes that these radar estimates have likely under-estimated the regional rainfall totals by a facto of 30 to even 50 percent in some locations. (Jordan Tessler/Capital Weather Gang)